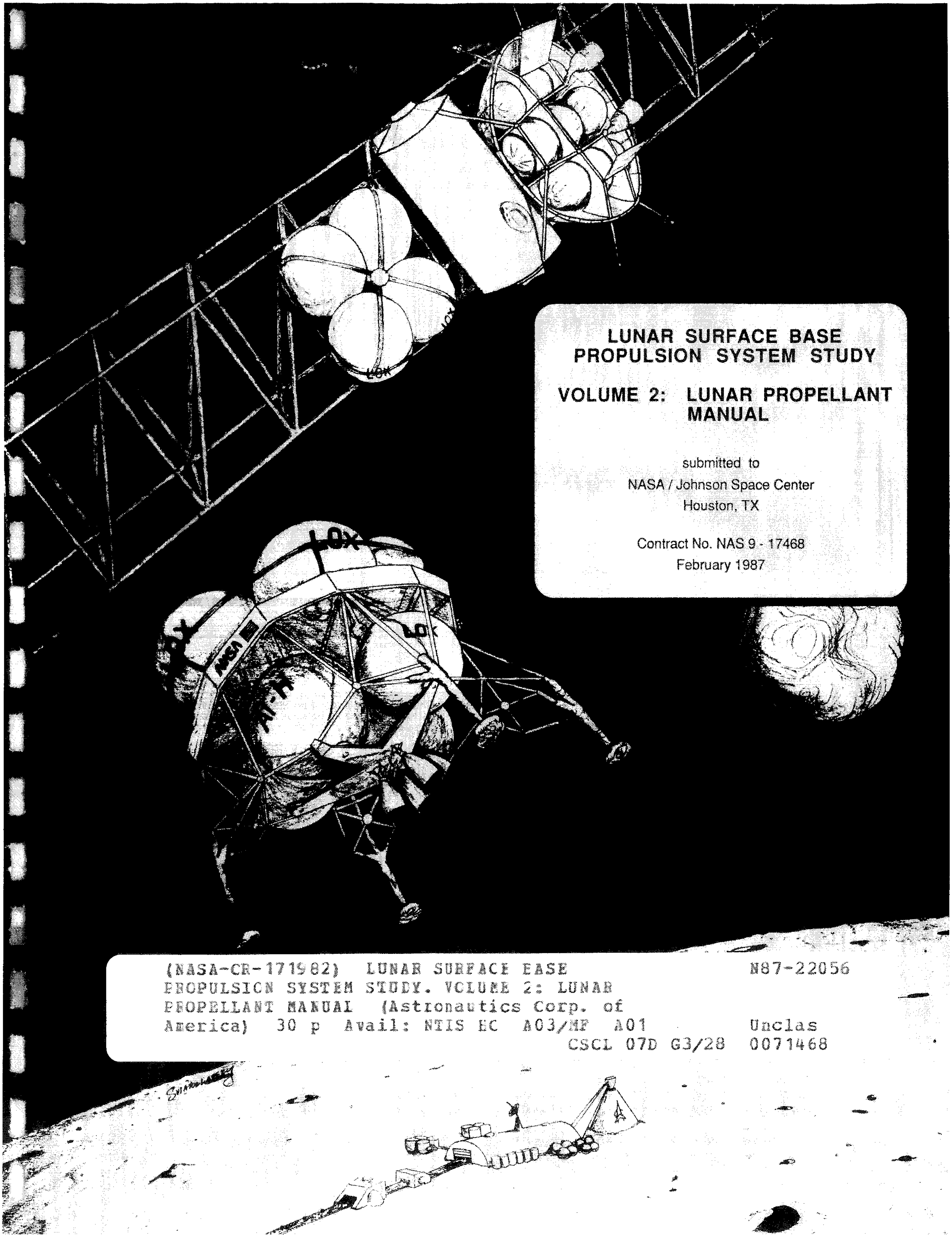


LUNAR SURFACE BASE PROPULSION SYSTEM STUDY

VOLUME 2: LUNAR PROPELLANT MANUAL

submitted to
NASA / Johnson Space Center
Houston, TX

Contract No. NAS 9 - 17468
February 1987

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LUNAR SURFACE BASE
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ABSTRACT

The efficiency, capability, and evolution of a lunar base will be largely dependent on the transportation system that supports it. Beyond Space Station in low Earth orbit (LEO), a Lunar-derived propellant supply could provide the most important resource for the transportation infrastructure. The key to an efficient Lunar base propulsion system is the degree of Lunar self-sufficiency (from Earth supply) and reasonable propulsion system performance. Lunar surface propellant production requirements must be accounted in the measurement of efficiency of the entire space transportation system. Of all chemical propellant/propulsion systems considered, hydrogen/oxygen (H/O) OTVs appear most desirable, while both H/O and aluminum/oxygen propulsion systems may be considered for the lander. Aluminized-hydrogen/oxygen and Silane/oxygen propulsion systems are also promising candidates. Lunar propellant availability and processing techniques, chemical propulsion/vehicle design characteristics, and the associated performance of the total transportation infrastructure are reviewed, conceptual propulsion system designs and vehicle/basing concepts, and technology requirements are assessed in context of a Lunar Base mission scenario.

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FOREWORD

This document represents Volume 2, the Lunar Propellant Manual of the Lunar Surface Base Propulsion System Study, Contract No. NAS9-17468. Volume 2 provides an initial compilation of potential Lunar-derived propellants. Volume 1 is the Final Report which provides detail of the study analyses and results. The contract effort was initiated on 15 January 1986 and continued through 15 February 1987.

The study was conducted by the Astronautics Corporation of America - Technology Center in Madison, Wisconsin. Aerojet TechSystems of Sacramento, California was a subcontractor contributing various propulsion and propellant analyses. Additional contributions were made by the Engineering Mechanics, Nuclear Engineering, and Chemistry Departments of the University of Wisconsin-Madison.

Comments or questions concerning this study effort should be directed to the NASA Technical Monitor, Leo R. Johnson at the NASA/Johnson Space Center; or to the Astronautics Project Manager, Ronald R. Teeter; or to the Deputy Project Manager, Thomas M. Crabb:

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1.0 CONSTITUENT PROPERTIES

All constituent properties were obtained using the Propellant Data Base at Astronautics Technology Center. The database runs on Lotus-1-2-3.

1.1 Properties

The properties included in the Propellant Database include:

- Molecular Weight
- Density
- Melting Point
- Boiling Point
- Heat of Fusion
- Heat of Vaporization
- Heat of Formation at 25C
- Free Energy of Formation at 25C

Values for these properties for chemical properllants analyzed in this study are listed in Table 1 below.

TABLE 1 PROPELLANT PROPERTIES

Chemical Formula	O_2	H_2	Al	Mg	SiH_4	Na
Molecular Weight	32.00	2.02	26.98	32.11	32.11	22.99
Density (g/cc)	1.149	0.070	2.699	1.739		0.965
Melting Point (deg C)	-218.40	-259.14	660.00	649.00	-185.00	97.98
Boiling Point (deg C)	-182.96	-252.80	2467.00	1090.00	-111.90	902.0
Heat of Fusion (J/mole)	441.83	116.40	10668.00	9042.29		
Heat of Vaporization (J/mole)	6799.12	916.55				97610.00
Heat of Formation (at 25C)	0.00	0.00	313800.00	150206.00	-61923.00	0.00
Free Energy of Formation (at 25C)	0.00	0.00	273150.00	115478.00	-39330.00	0.00

Values for these properties were obtained from "CRC Handbook of Chemistry and Physics", "Thermodynamic Properties of Minerals and Related Substances at 298.15K and 1 Bar (10 5 Pacals) Pressure and at Higher Temperatures" by the U.S. Geological Survey, the Joint Army, Navy, NASA, Air Force (JANNAF) propellant manuals and the Chemical Propulsion Information Agency's "Liquid Propellant Manual".

1.2 Database Description

The Propellant Database runs on Lotus 1-2-3. The database also may include properties such as toxicity, reactivity and others for each propellant. The information in the database can be arranged or sorted using the function keys programmed into the database.

2.0 THEORETICAL PERFORMANCE

2.1 Hydrogen/Oxygen Propulsion

TABLE 2. H/O Isp vs Nozzle Area Ratio
(MR = 5, Pc = 1000)

Isp	E
441	20
455	40
469	100
477	200
483	300

See Figure 1.

TABLE 3. H/O Isp vs Chamber Pressure
(MR = 5, E = 100)

Isp	Pc
468	100
468.8	300
469.2	500
469.5	1000

See Figure 2.

TABLE 4. H/O Isp vs Mixture Ratio
(E = 100, Pc = 100)

Isp	MR
456	3
466	4
469.5	5
468	6
463.5	7
453	8

See Figure 3.

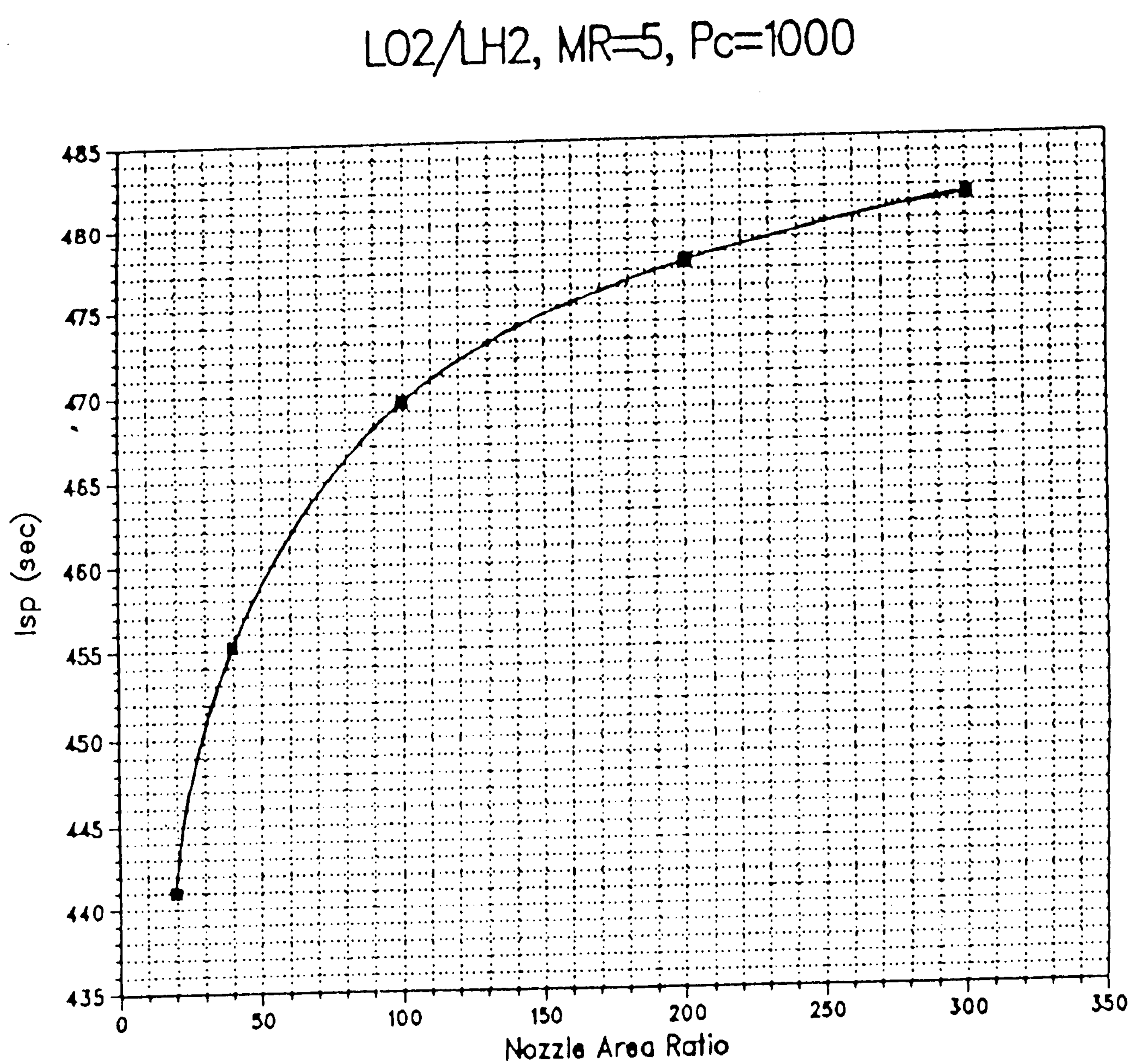


FIGURE 1. H/O Isp VERSES EXPANSION RATIO

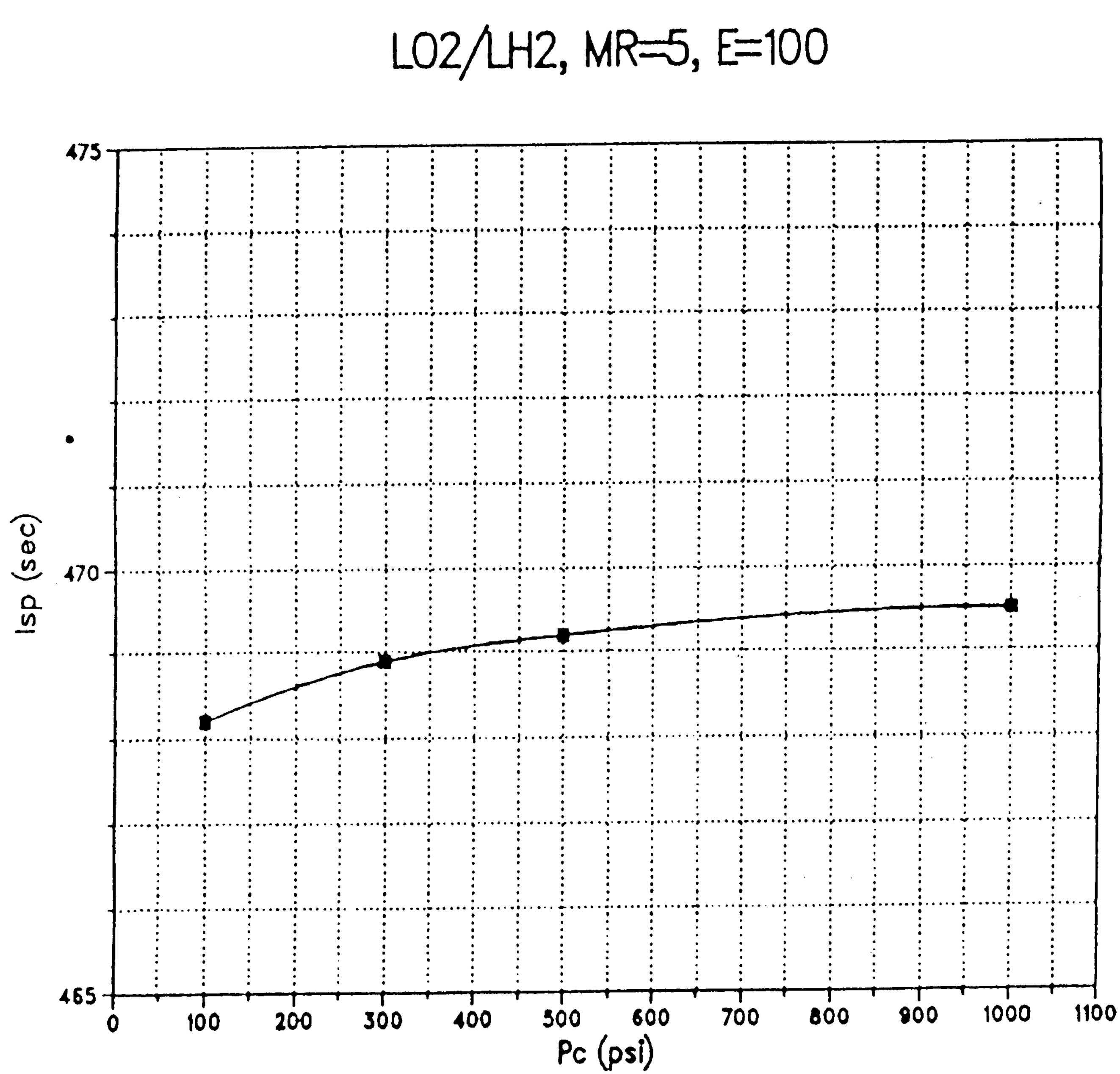


FIGURE 2. H/O Isp VERSES CHAMBER PRESSURE

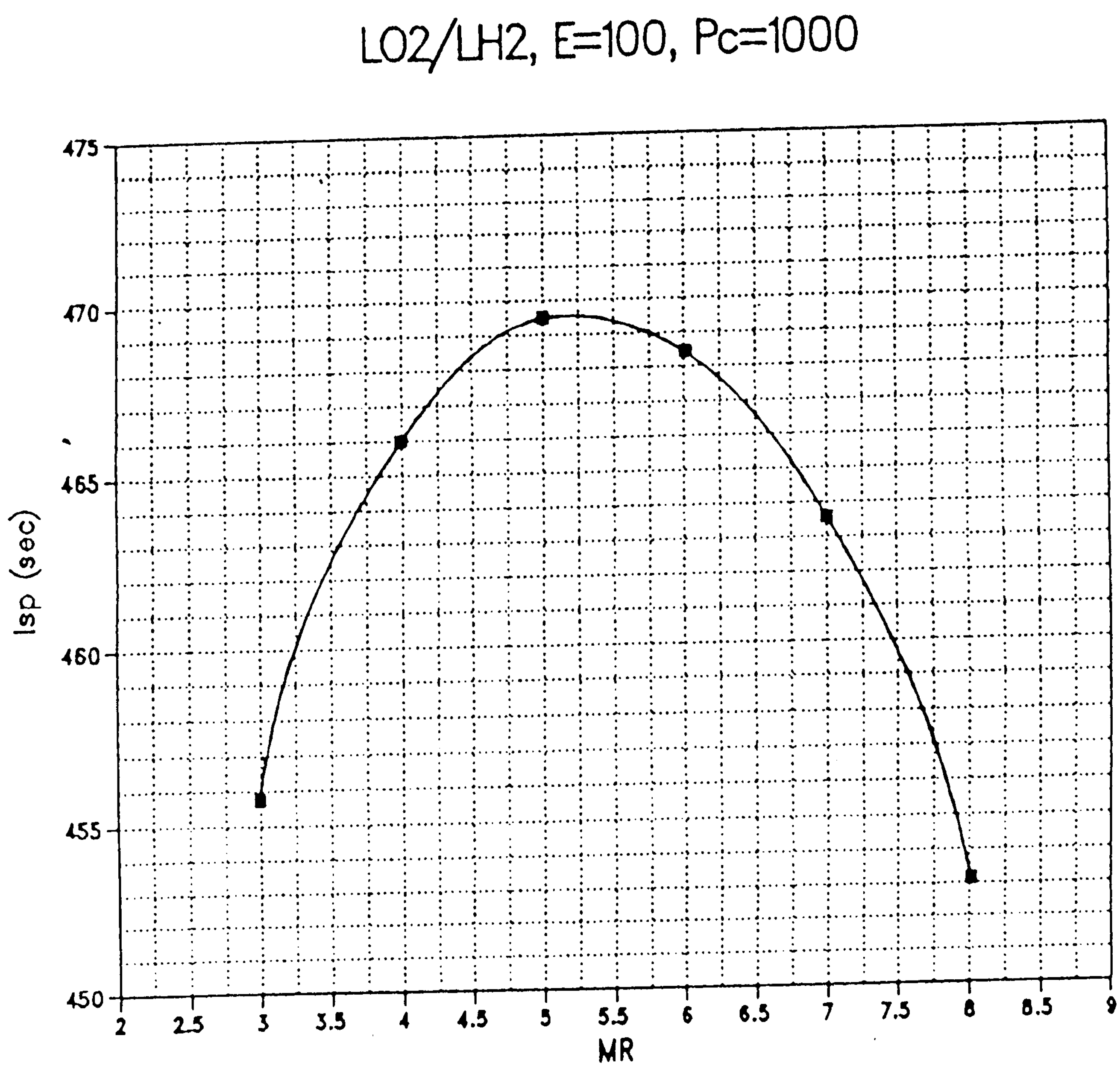


FIGURE 3. H/O Isp VERSES MIXTURE RATIO

2.2 Aluminum/Oxygen Propulsion

TABLE 5. Al/O Isp vs Nozzle Area Ratio
(MR = 2.3, Pc = 1000)

Isp	E
260	20
277.5	50
288	100
295	150
297.5	200

See Figure 4.

TABLE 6. Isp vs. Chamber Pressure
(MR = 2.3, E = 100)

Isp	Pc
284.3	100
287.4	500
288.0	725
288.6	1000
289.3	1500

See Figure 5.

TABLE 7a. Isp vs. Mixture Ratio
(E = 20, Pc = 500)

Isp	MR
256	2
259.3	2.3
259.4	2.5
259.1	2.7

See Figure 6a.

Table 7b. Al/O Isp vs Mixture Ratio
(E = 100, Pc = 1000)

Isp	MR
287.5	1.9
288.3	2.1
288.6	2.3
288.4	2.5
288.0	2.7

See Figure 6b.

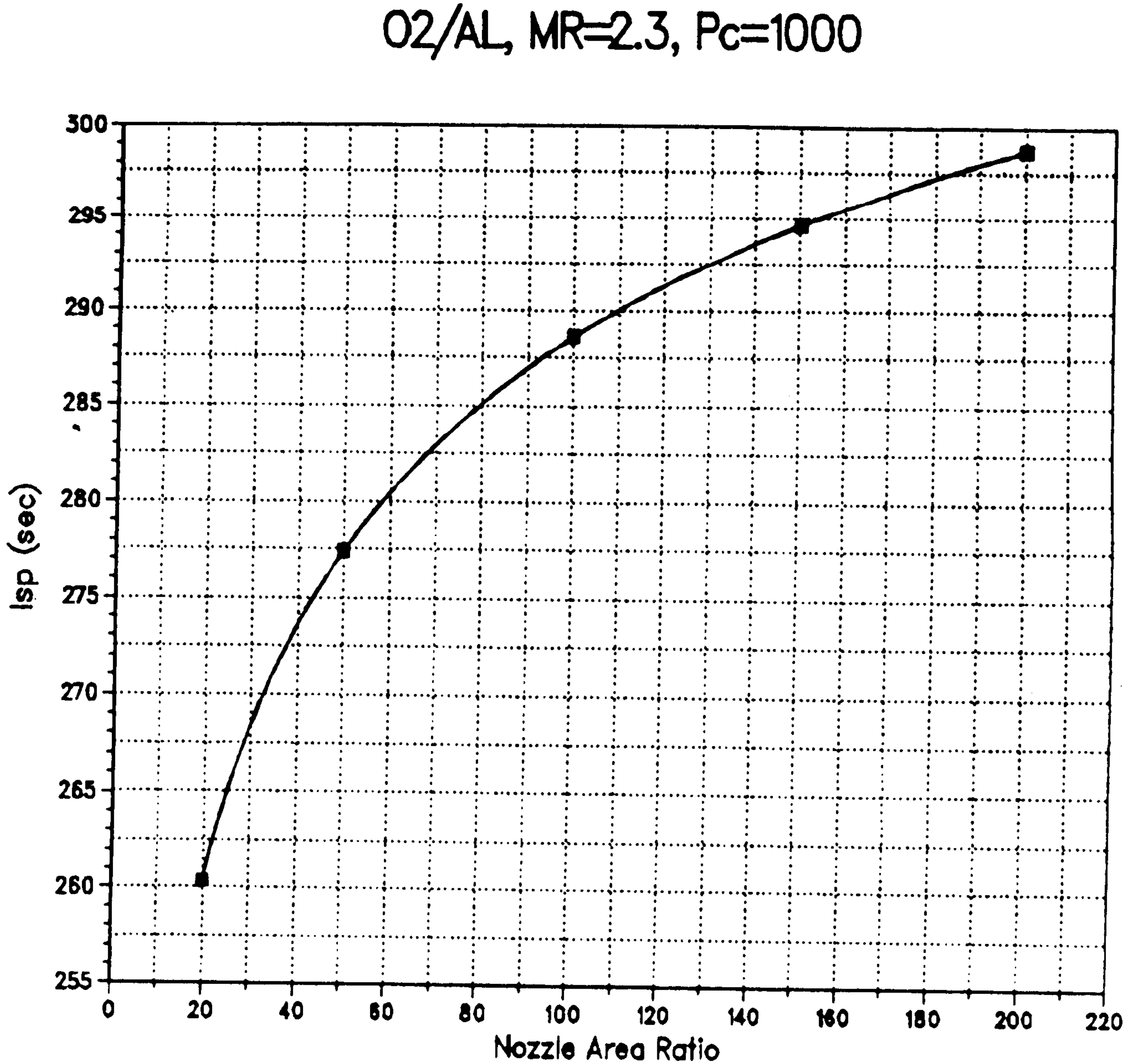


FIGURE 4. Al/O Isp VERSES NOZZLE AREA RATIO

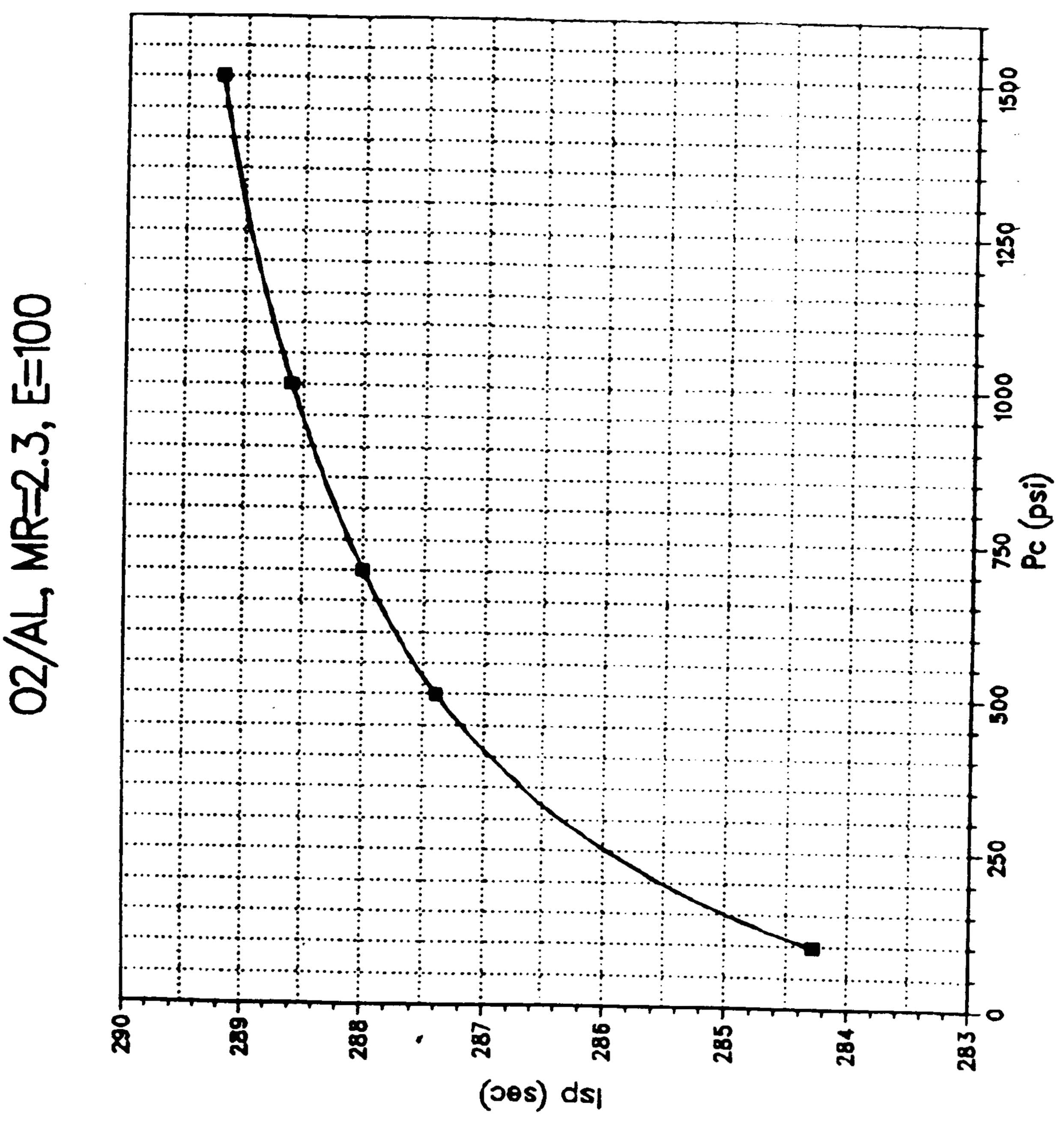


FIGURE 5. Al/O Isp VERSES CHAMBER PRESSURE

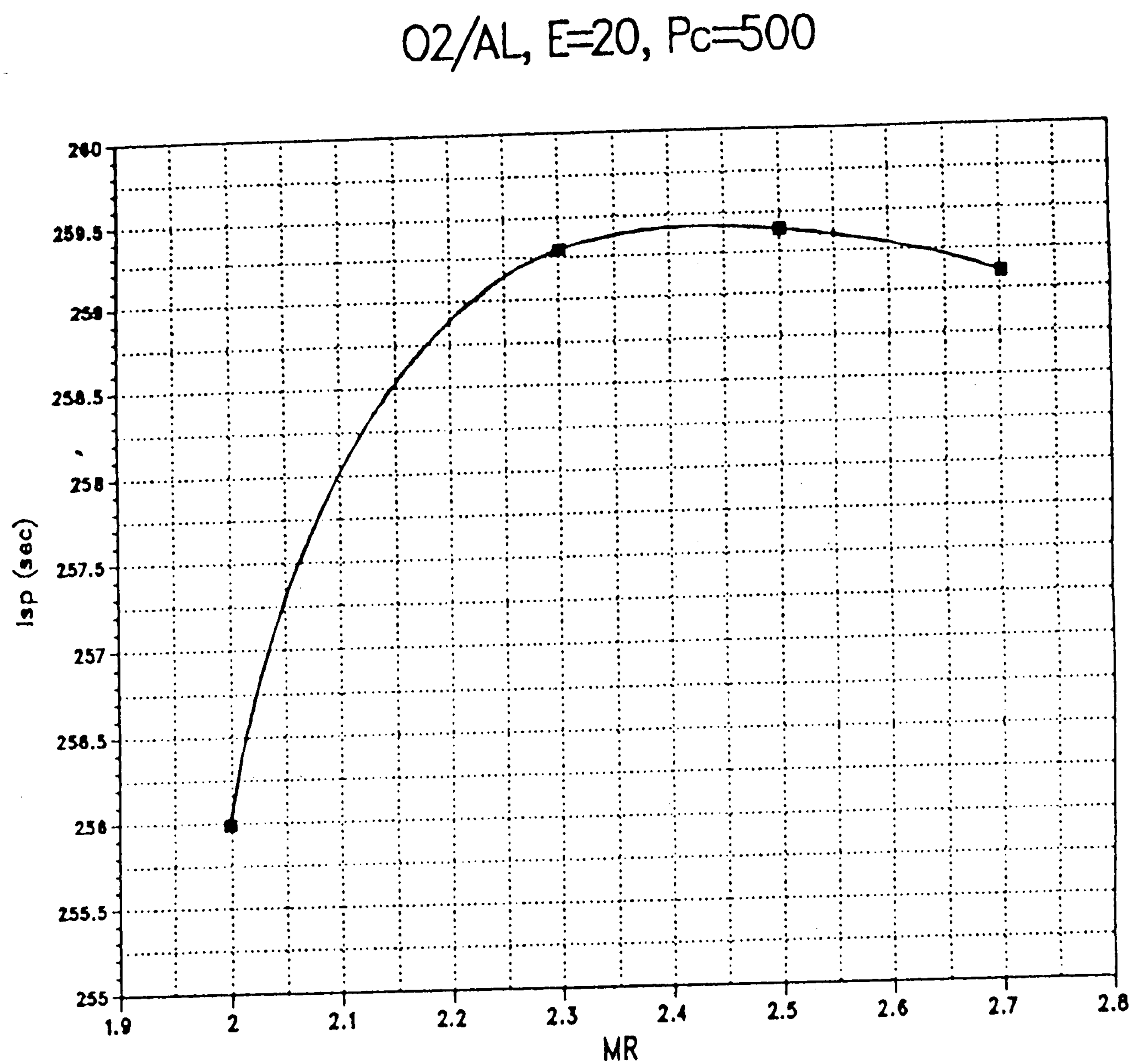


FIGURE 6a. Al/O Isp VERSES MIXTURE RATIO

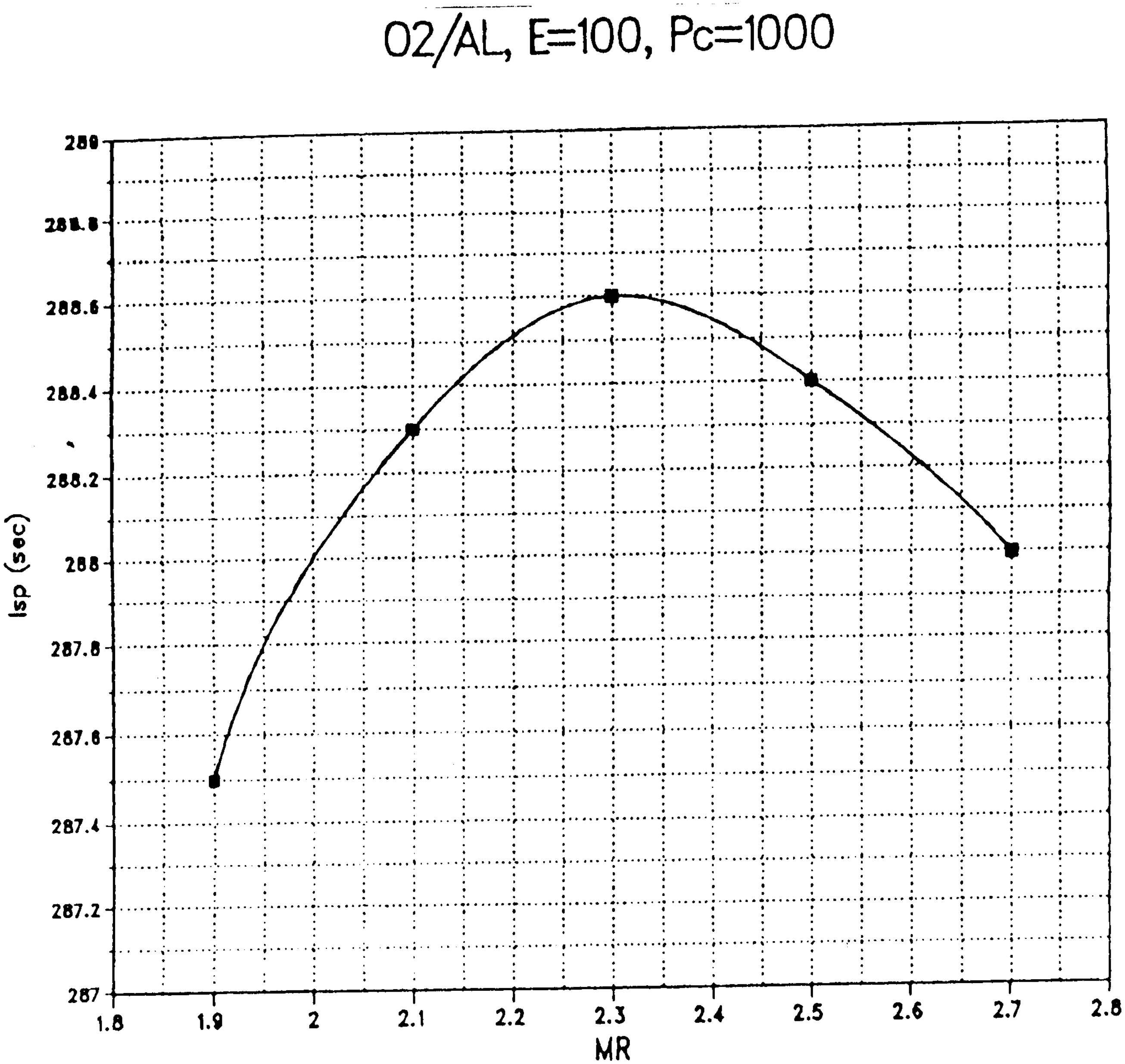


FIGURE 6b. Al/O Isp VERSES MIXTURE RATIO

2.3 Aluminized-Hydrogen/Oxygen Propulsion

TABLE 8. Al-H/O Isp vs Mixture Ratio
(Pc = 1000, E = 100, 6% LH_2 + 40% Al)

Isp	MR
453	1
470	2
472.2	2.4
472.4	2.6
472.1	2.7
471.0	3
456	4
448	5

See Figure 7.

2.4 Aluminum-Magnesium/Oxygen Propulsion

TABLE 9. Al-Mg/O Isp vs Percent Aluminum
(MR = opt, Pc = 1000, E = 100)

Isp	%Al
279	25
281.8	50
286.8	80
288.6	100

See Figure 8.

2.5 Silane/Oxygen Propulsion

TABLE 10. SiH_4/O Isp vs Mixture Ratio
(E = 20, Pc = 500)

Isp	MR
350.9	0.75
351.6	0.8
351.5	0.85
351.0	0.9
549.7	1

See Figure 9.

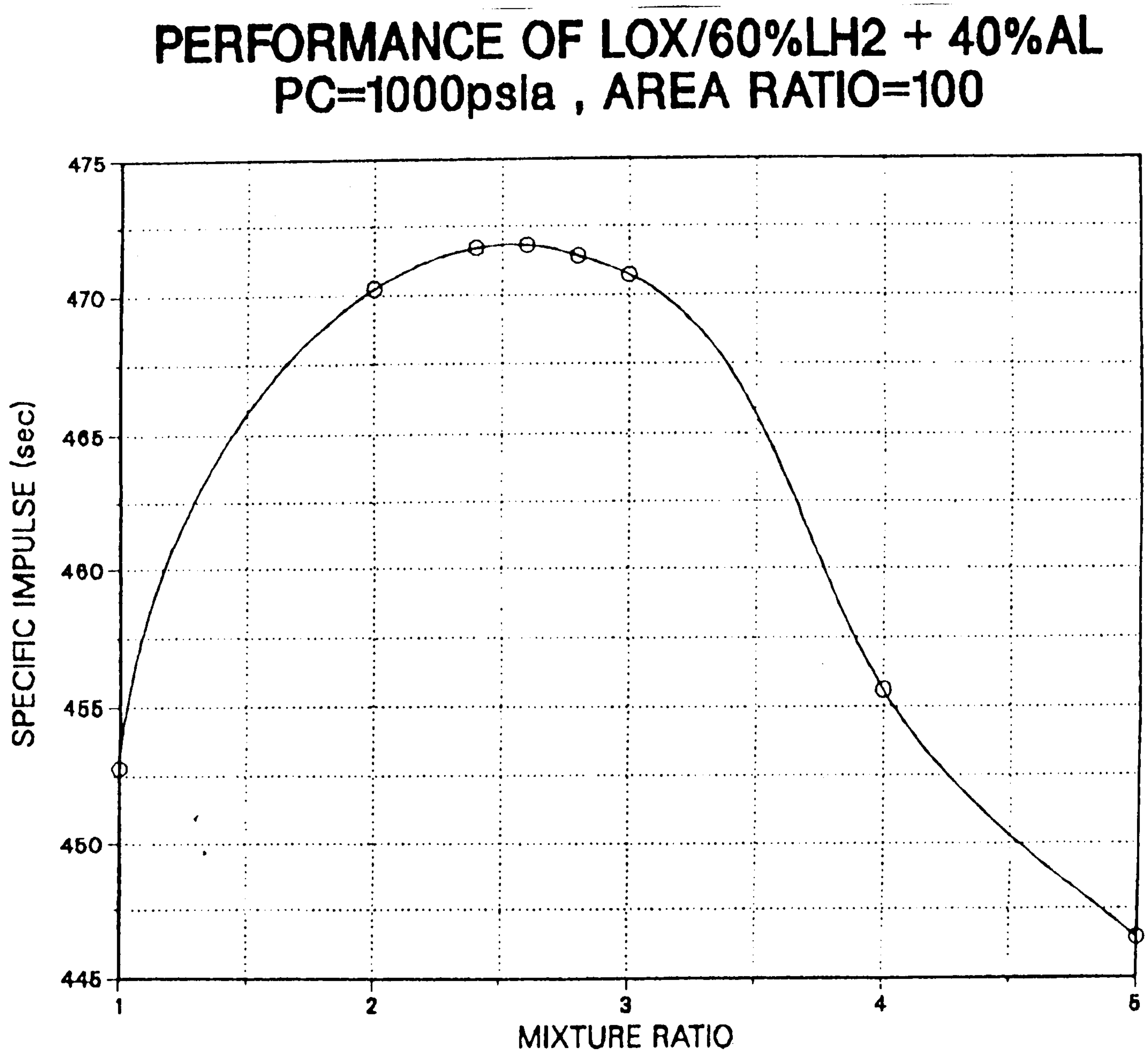


FIGURE 7. Al-H/O Isp VERSES MIXTURE RATIO

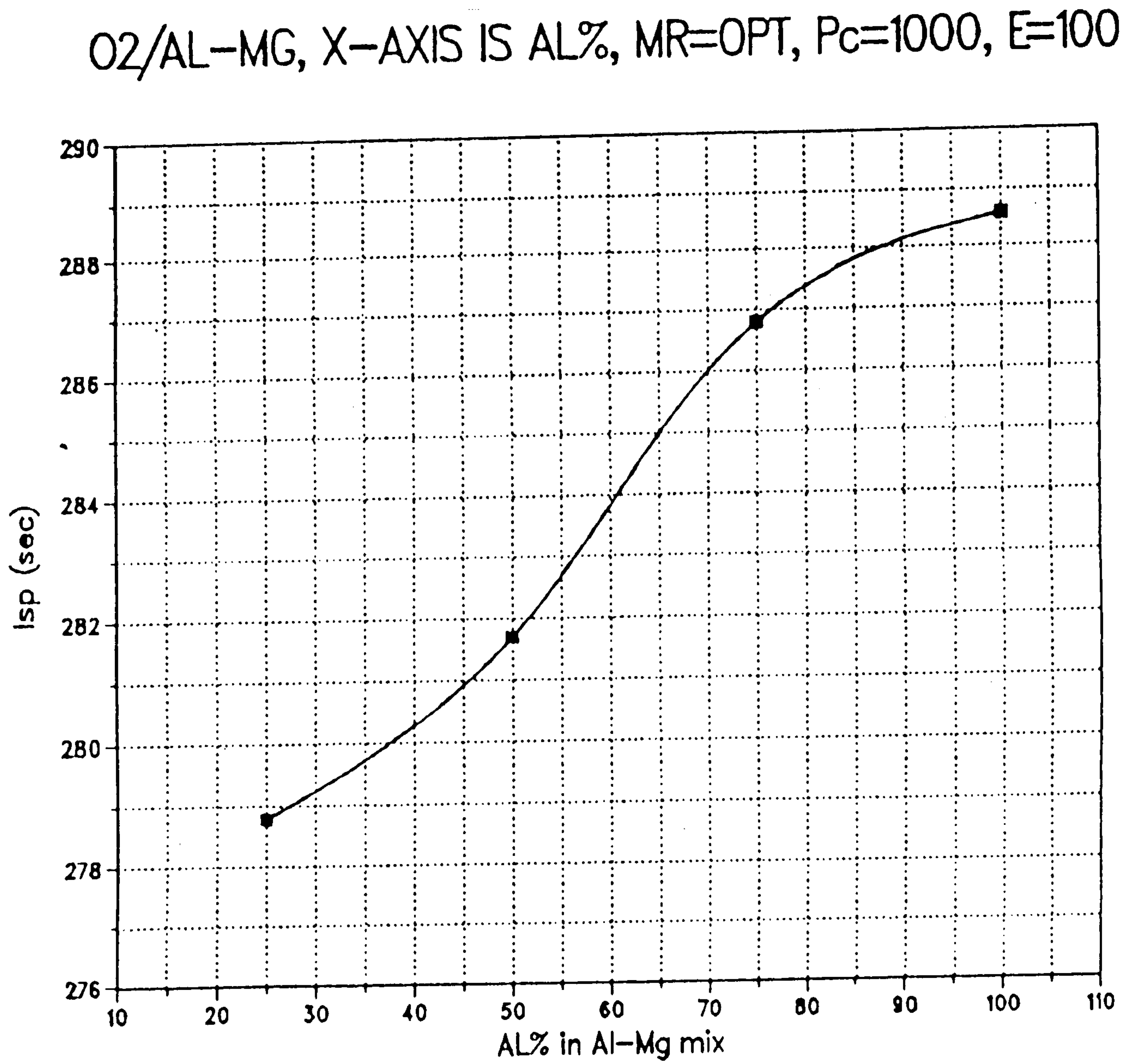


FIGURE 8. Al-Mg/O Isp VERSES PERCENT ALUMINUM

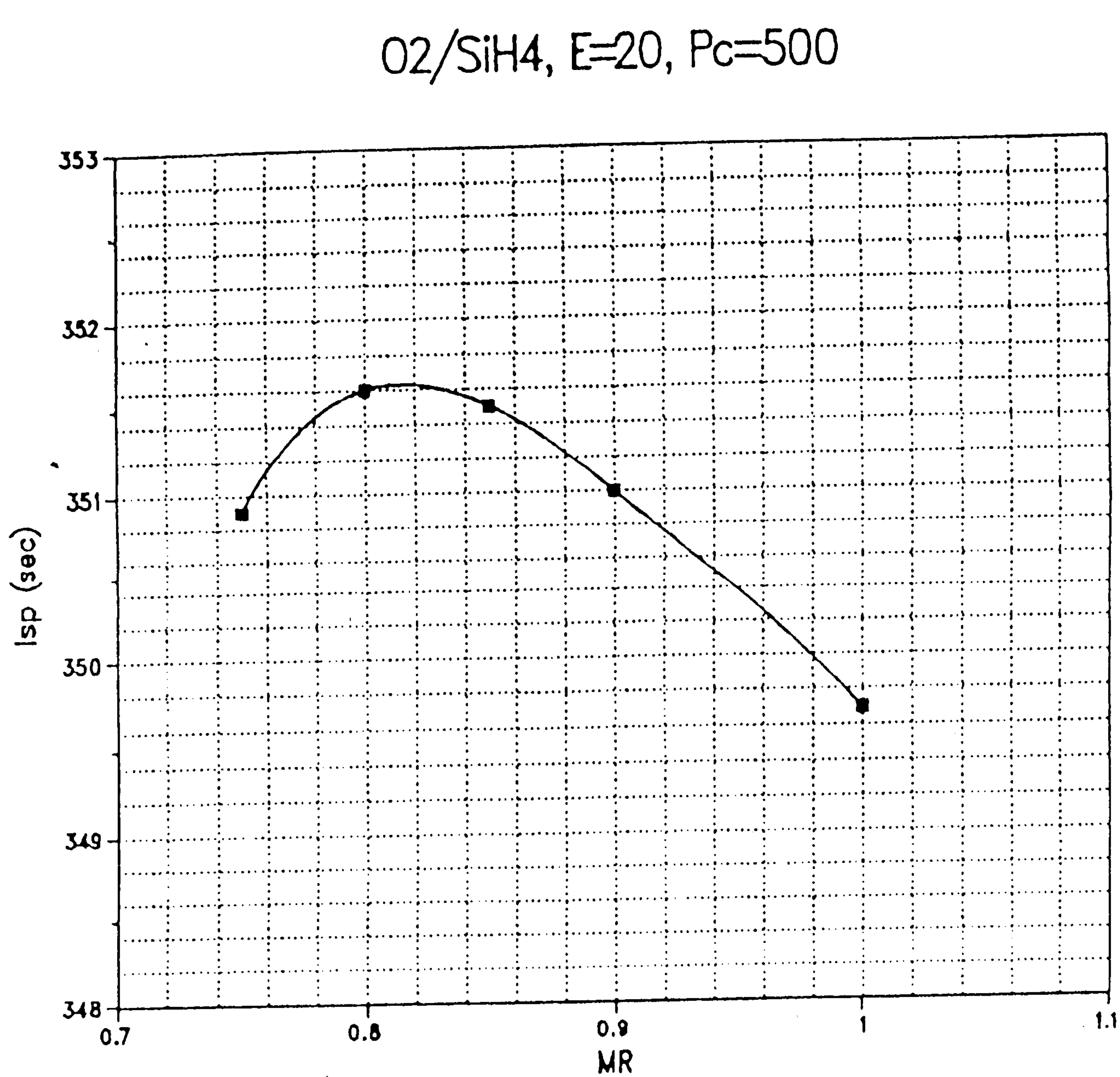


FIGURE 9. SiH4/O Isp VERSES MIXTURE RATIO

TABLE 11. SiH_4 Isp vs Mixture Ratio
(E = 100, Pc = 100)

Isp	MR
387.8	0.75
391.3	0.80
391.8	0.85
391.5	0.90
390.9	0.95

See Figure 10.

TABLE 12. SiH_4 Isp vs Nozzle Area Ratio
(MR = .85, Pc = 1000)

Isp	E
354	20
377	50
392	100
400	150
405	200

See Figure 11.

TABLE 13. SiH_4 Isp vs Chamber Pressure
(MR = 0.85, E = 100)

Isp	Pc
381.6	100
388.8	500
390.2	700
391.8	1000
393.8	1500

See Figure 12.

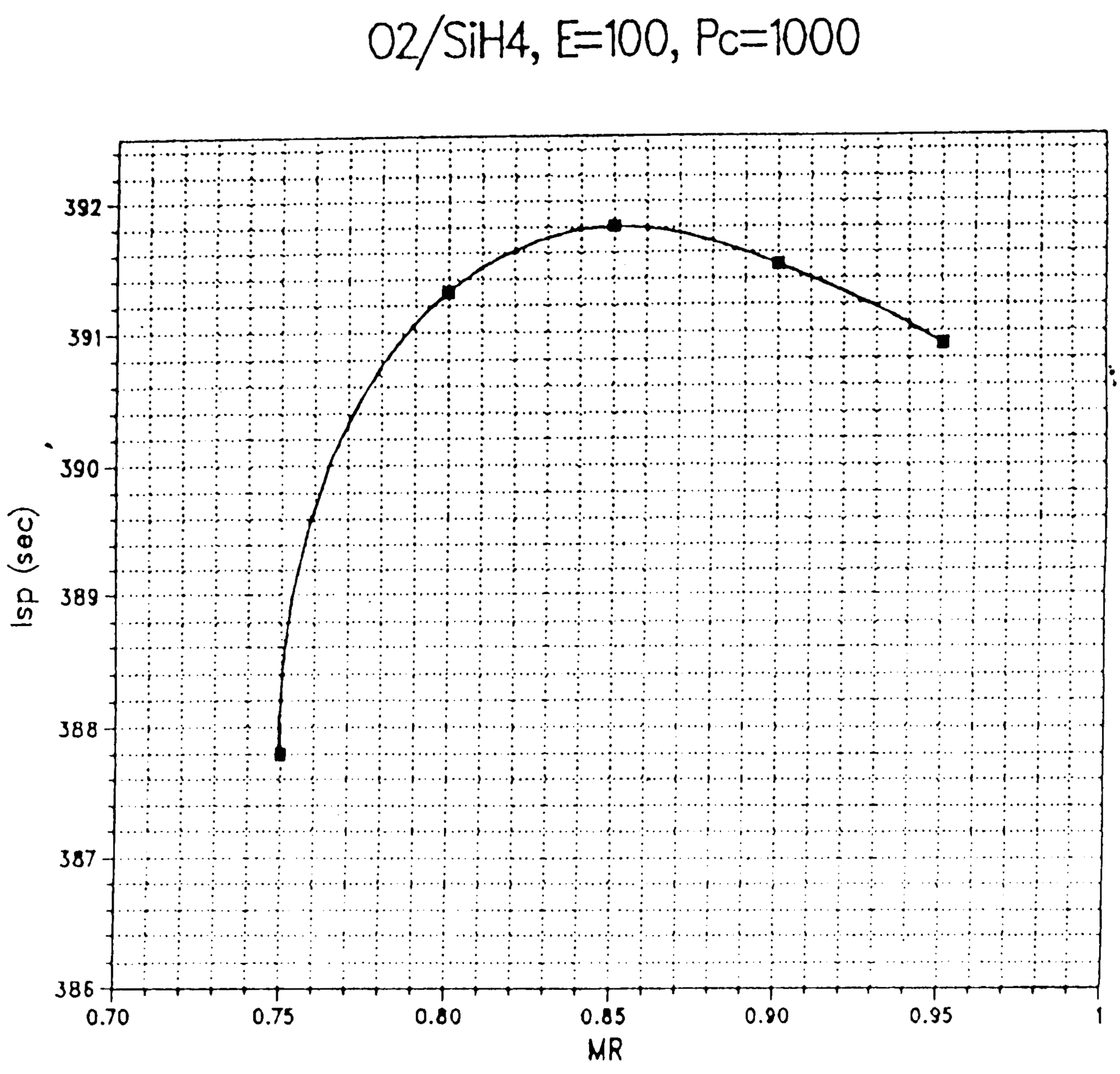


FIGURE 10. SiH4/O Isp VERSES MIXTURE RATIO

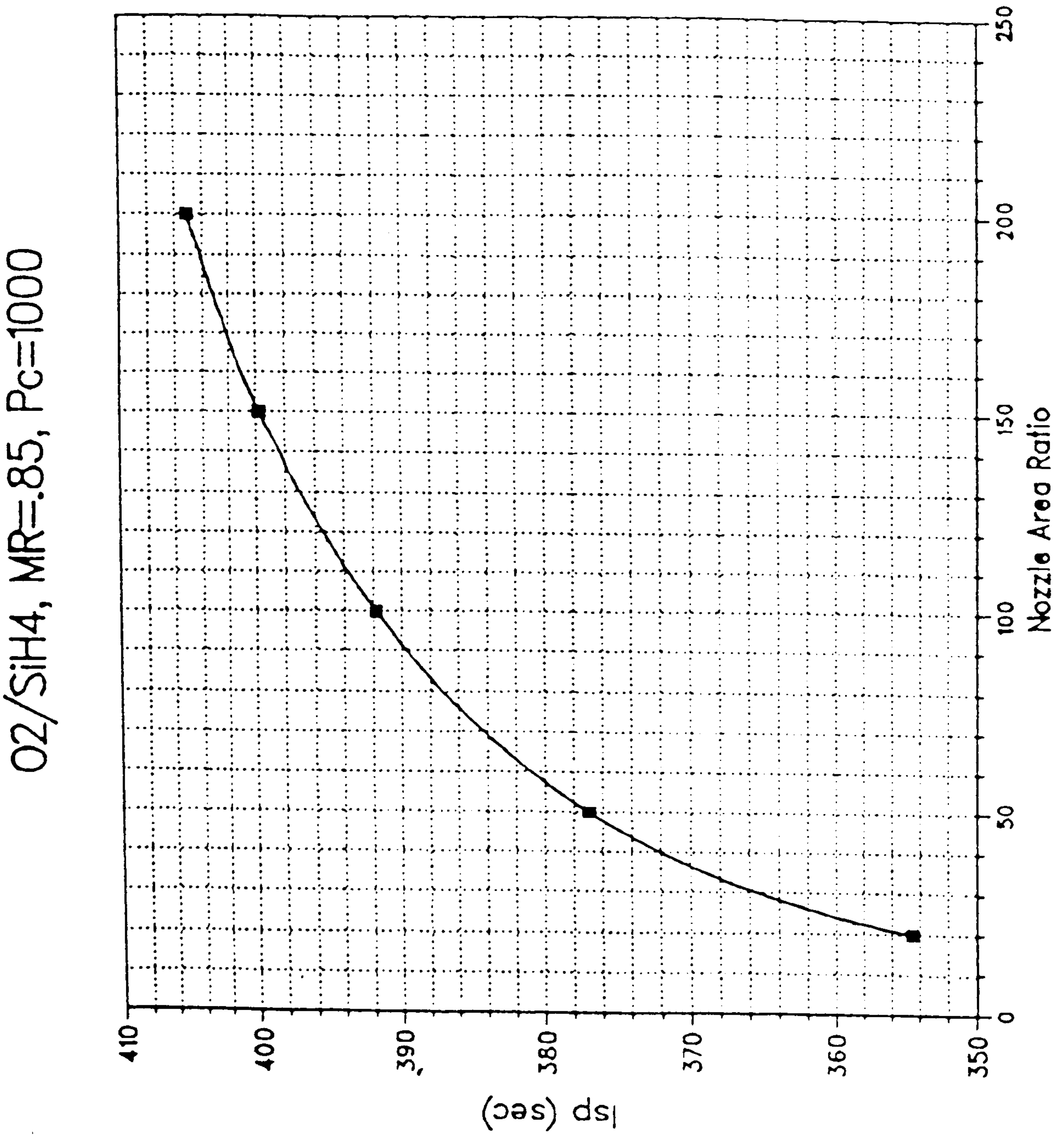


FIGURE 11. SiH4/O Isp VERSES NOZZLE AREA RATIO

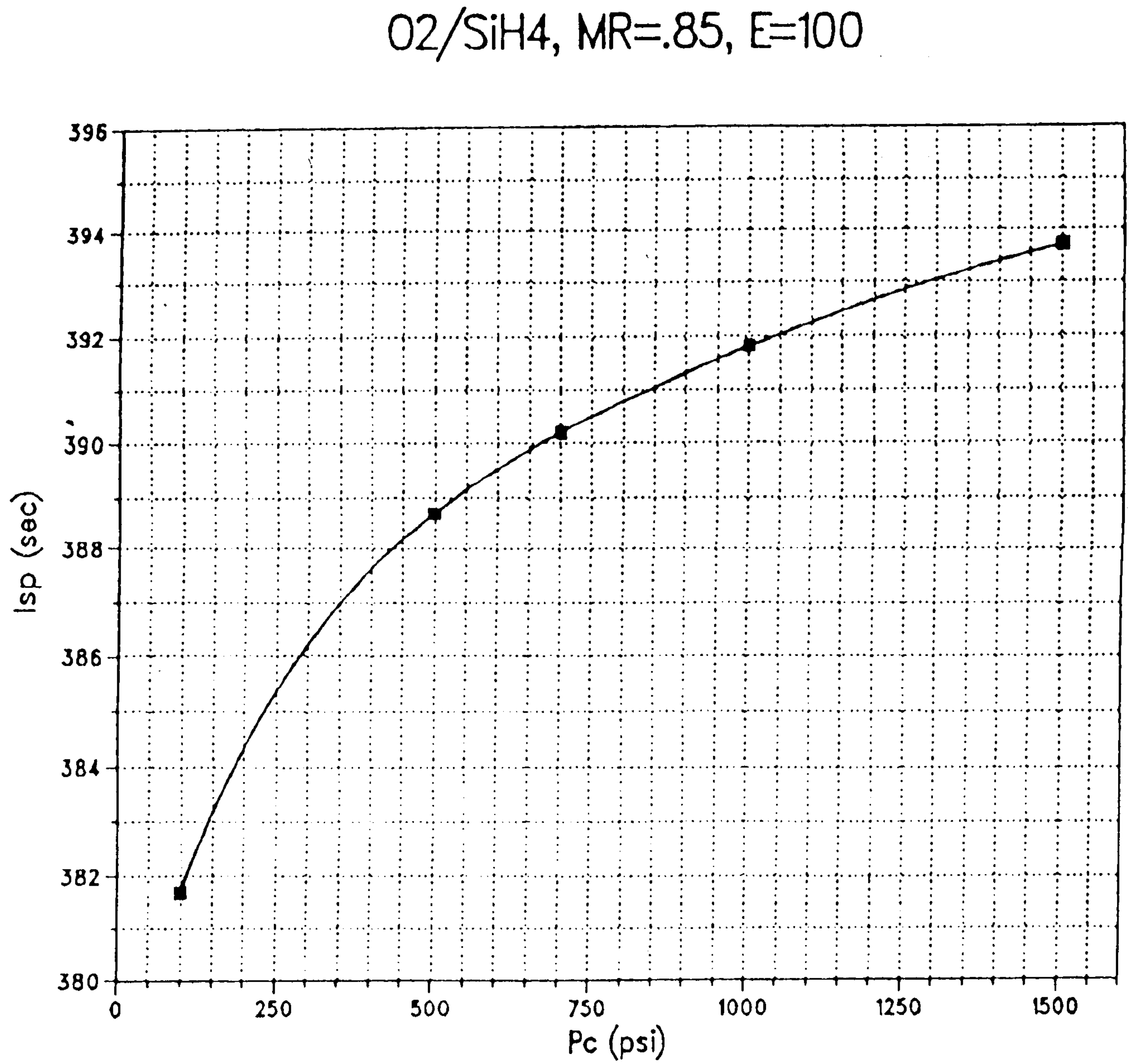


FIGURE 12. SiH4/O Isp VERSES CHAMBER PRESSURE